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Diseases of Cultivated Guayule and Their Control¹

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IMPORTANCE OF GUAYULE DISEASES

The world-wide interest in rubber-producing plants adapted to temperate climates is reflected in the number of publications on guayule (*Parthenium argentatum* A. Gray) appearing in the past 40 years. In 1942 Moyle (11)² listed more than 100 references dealing wholly or partly with guayule.

In natural stands guayule is relatively free of diseases; in fact, in 1911 Lloyd (9) listed only one fungus disease, a rust of minor importance. In 1942, when the Emergency Rubber Project was created to expand the production of guayule as a wartime source of rubber, little was known about its diseases under cultivation. Almost all information on such diseases has resulted directly or indirectly from the activities of the Emergency Rubber Project. Exceptions are an indefinite reference to diseases of guayule in Italy by Guglielminetti (5) in 1936, the listing of it in the same year as moderately susceptible to *Phymatotrichum* in Texas (14), a brief reference in 1941 to an unidentified root rot in California (13), and the reports of phymatotrichum root rot and of an unidentified crown rot in Texas in 1943³ and of a leaf spot caused by *Ramularia* in Australia (15). The data on guayule diseases reported in this circular were accumulated between 1942 and 1945 from observations of nurseries on 2,000 acres and of field plantings on 30,000 acres and from greenhouse, laboratory, and field experiments.

On most irrigated and nonirrigated, well-drained soils loss from disease was not an important factor in the production of nursery or field-grown guayule. However, serious disease losses occurred in localized areas on poorly drained soils under irrigation and on well-drained soils when excessive amounts of water were applied. Careful control of irrigation was found necessary to avoid disease loss on many irrigated plantings.

In the nurseries seedling-emergence failure was of common occurrence during cool periods when night temperatures dropped below 50° F. Satisfactory nursery stands were readily obtained if the minimum air temperatures were 50° or above and the maximum air temperatures did not rise greatly above 90°. Seedling root rot caused by *Pythium ultimum* Trow and splash injury were often responsible for considerable mortality in seedlings less than 6 weeks old. These diseases were aggravated by high soil moisture and watering practices.

Pink rot caused by *Pythium ultimum* was prevalent in all nurseries, affecting seedlings from 6 to 16 weeks old, but it did not result in serious loss. Sclerotinia rot caused by *Sclerotinia sclerotiorum* (Lib.) D By. and *S. minor* Jagger was the most serious disease affecting seedlings from 5 to 8 months old. Minor losses in this age group were also caused by *Botrytis cinerea* Pers. Losses from these diseases were usually associated with high humidity and high soil moisture, and satisfactory control was effected by regulation of irrigation practices.

Wilt caused by *Verticillium albo-atrum* Reinke and Berth. was present in localized areas in the nurseries. The most severely infested areas were abandoned for nursery-stock production after the first season.

Sclerotinia and botrytis rots destroyed considerable planting stock in cold storage. These rots were particularly active in crated plants that were moist when packed and held under poor storage conditions. Losses from

² Italic numbers in parentheses refer to Literature Cited, p. 42.

³ EZEKIEL, W. N. CROWN ROT AND ROOT ROT OF GUAYULE. U. S. Bur. Plant Indus., Plant Dis. Rptr. 27: 2-8, illus. 1943. [Processed.]

these rots were reduced to a minimum when disease-free plants were crated free of surface moisture and placed in cold storage at temperatures from 32° to 34° F.

Root rots cause most of the disease loss in guayule plantations. The organisms that cause root rot occasionally attack the crown (juncture between stem and root); therefore, the term "root rots" includes diseases that may affect either the roots or the crown of the plant. In field plantings a root rot caused by *Phytophthora drechsleri* Tucker was prevalent and occasionally destructive on irrigated lands, especially on poorly drained soils. Losses from the disease were experienced in all areas where guayule was grown under irrigation. Careful control of irrigation during hot weather was found necessary in order to avoid losses from phytophthora root rot and drowning. Considerable loss from root rot caused by *Phymatotrichum omnivorum* (Shear) Dugg. occurred on irrigated fields in southern Texas. However, this disease has not been serious on dry-land plantings in that State.

Verticillium wilt was common on field plantings in the Bakersfield district of California. Strain 109 proved to be highly susceptible to the disease, but strain 405 was resistant under the same conditions. Strain 593, the one commonly planted, was intermediate in susceptibility.

Other diseases known to affect field-planted guayule include a crown rot caused by *Sclerotium bataticola* Taub., which developed on dry-land plantings in Texas during prolonged hot, dry weather; a root rot caused by *Sclerotinia* spp. in California and Arizona; a root rot caused by *Sclerotium rolfsii* Sacc., which occurred to a limited extent in Arizona and Texas; a root rot caused by an unidentified bacterium in California and Texas; a die-back caused by *Diplodia theobromae* (Pat.) Nowell, which affected succulent plants in southern Texas during rainy periods in the summer and fall; and a rust caused by *Puccinia parthenii* Arth., which has been observed in Mexico but is not known on guayule in the United States.

NURSERY PRACTICES IN RELATION TO DISEASES

From 1925 to 1942 the Intercontinental Rubber Co. maintained at Salinas, Calif., a nursery where guayule seedlings were produced for plantations and for trial plots in the State and elsewhere in the Southwest. Ordinarily a surplus of seedlings was produced, and losses from disease rarely interfered with the planting program. The principal disease to attract attention was a root rot that affected the plants in wet years. This rot was exceptionally severe in the spring of 1942, when the Forest Service took over the production of guayule as an emergency source of rubber.

In 1942 the guayule nursery area in the Salinas Valley was increased from approximately 25 to 500 acres, and in the following year the nursery area in California was expanded to more than 1,500 acres on a variety of soils and under diverse climatic conditions by establishing additional nurseries near Bakersfield, Indio, and Oceanside. Because cultivated land could be quickly converted into nurseries, sites were selected that had previously been planted to such crops as lettuce, sugar beets, cotton, alfalfa, and beans.

Observations from 1942 to 1944 demonstrated that nursery-grown guayule and that seeded direct in the field were susceptible to several of the diseases common to crop plants, especially those caused by soil-inhabiting fungi. Although the total disease loss was relatively small, considering the size of the nurseries, severe losses were experienced in localized areas. The most serious nursery diseases of guayule were caused by fungi; thus far no virus

diseases⁴ and no serious nursery diseases attributable to bacteria have been recognized.

Certain diseases that affect nursery plants are aggravated by cultural practices. In order to explain better the relation of these practices to the prevalence and severity of diseases, the arrangement of the nursery beds, watering practices, and methods of handling and treating seed are briefly described.

The guayule nurseries established by the Forest Service were patterned after those commonly used in the production of forest-tree planting stock. Ten nurseries or nursery units were in operation in California in 1943. The Santa Rita, Alisal, and Quail Creek nurseries were near Salinas; the Lee and Caliente units of the Bakersfield nursery were near Bakersfield; the Bell and Whittier units of the Indio nursery were near Indio; and the Mission, Carlsbad, and San Mateo nurseries were in the general vicinity of Oceanside.

Each nursery was divided into units termed "blocks." A standard block comprised slightly more than 3 acres, but considerable variation existed in size, especially in the Alisal nursery, where blocks ranged from 2 to 5 acres in extent. The nurseries were provided with overhead irrigation pipes supported on posts approximately 6 feet in height. In order to reduce air movement over the beds snow-fence windbreaks were fastened to each line of posts supporting the sprinklers.

Each block was divided into sections corresponding to the area between 2 rows of irrigation pipes. A standard section in 1942 included 10 beds, each 400 feet long and 4 feet wide, separated by duckboards 8 inches wide. In 1943 the use of duckboards was discontinued except on the heavier soils and the number of beds per section was reduced to 9. The beds were separated by paths 12 to 14 inches wide, corresponding to the width of the tractor wheels.

A special seeding machine deposited the seed in 7 parallel bands per bed and covered each band lightly with sand. This arrangement of the seed permitted cultivation for weed control and the application of fertilizer in drills during the growing season. Although the rate of seeding was calculated to produce approximately 25 seedlings per square foot, variations in seed lots, temperature, and other factors resulted in many beds with either more or fewer plants per unit area than was considered desirable.

In 1942 all seed was washed for 18 hours in running water and soaked for 2 hours in a sodium hypochlorite solution containing 1.5 percent of available chlorine. After thorough rinsing the seed was dried at 113° F. and before seeding was pregerminated for 5 days at approximately 75°. In 1943 hypochlorite-treated seed was again used, but instead of being pregerminated for 5 days it was moistened and held at 75° for 2 to 3 days before seeding. In both 1942 and 1943 the seed was not permitted to dry before seeding. The beds were irrigated shortly after seeding and four or five times a day thereafter until the seedlings had emerged. The period of frequent irrigations varied from 8 to 15 days, depending upon temperature. In general, if the minimum air temperatures were 50° or above, a satisfactory stand was obtained in 8 to 10 days. After the seedlings had emerged the frequency of irrigations was gradually reduced.

⁴H. H. P. Severin and J. H. Freitag, Division of Entomology and Parasitology, University of California, tested the susceptibility of guayule to a large number of the common virus diseases.

The agronomy section of the Special Guayule Research Project has developed a method of producing nursery stock without the use of overhead irrigation. This method consists essentially in direct seedings in which moisture for germination is supplied in shallow furrows. It is entirely suitable for growing seedlings for transplanting and eliminates the necessity for expensive nursery installations.

GENERAL PREVENTIVE MEASURES AGAINST NURSERY DISEASES

Diseases once established in a nursery are often difficult to control and usually impossible to eradicate. The greatest opportunity for disease control comes in the selection of a disease-free nursery site and in the observance of sanitation practices to prevent the introduction and spread of pathogenic organisms. Since the best disease control is disease prevention, methods of preventing nursery diseases are emphasized.

FACTORS IMPORTANT IN SELECTION OF SITES

SOILS

Experience has shown that good guayule planting stock can be produced on fertile, well-drained soils. A sandy loam or a similar well-drained soil is satisfactory and has the advantage of warming up early in the spring and reducing damping-off hazards during and after seedling emergence. A coarse sandy soil is undesirable because it predisposes the seedlings to drought injury and to certain deficiency diseases. Heavy soils are particularly objectionable for guayule nurseries, because they are difficult to manage, waterlog readily, and often develop conditions favorable for root rot.

WATER SUPPLY

An adequate water supply is essential in the production of guayule nursery stock. The frequent irrigations required to obtain emergence tend to accumulate salts in the upper layers of soil; therefore, a high salt content of the water or of the soil is undesirable. On the other hand, guayule has been shown to have a wide tolerance range to boron, which may make it suitable for planting in areas where the water supply or the soil has a relatively high boron content (10).

PREVIOUS CROP HISTORY

The previous crop history of a proposed nursery site should be thoroughly investigated. Special attention should be given to records of crop losses. If abrupt changes have been made in the kind of crops raised, it should be ascertained whether disease rendered the previously grown crops unprofitable or the change was due to other factors. Cropland with a past history of *Sclerotinia* or *Verticillium* infestations should not be used for guayule nurseries. If the disease history is unknown, then land long devoted to lettuce, cotton, tomatoes, or other susceptible truck crops should be investigated for the presence of these fungi before it is selected. Old sugar-beet fields should be discriminated against because of the possibilities of infestation with *Sclerotium rolfsii*.

NEMATODES

Swelling, or knots, on the roots of crop plants are often caused by the root knot nematode (*Heterodera marioni* (Cornu) Goodey). Some crops are severely affected, whereas others are relatively resistant to attack. Allen⁵

⁵ ALLEN, M. W. ROOT KNOT NEMATODE INFECTION OF GUAYULE. Emergency Rubber Project Rptr. 1944. [Unpublished.]

and Hoyman (6) have shown that guayule is resistant to root knot nematodes. The presence of nematodes in a nursery, however, may restrict the distribution of stock because of State quarantine regulations. Therefore, nematode-infested land should be avoided for a nursery if the stock is to be distributed outside of the State in which it is grown or is to be planted on noninfested land. Nematode-infested land may be justified for nurseries only if the stock is to be planted on nearby land already known to be infested with nematodes.

PROXIMITY TO FIELD PLANTINGS

Insofar as practical nurseries should be located near the areas in which the seedlings are to be planted. This will avoid the necessity for long hauls by truck or rail with the attendant danger from heating, drying, and diseases. The shorter the interval between digging and planting the less opportunity for deterioration from drying or diseases. Furthermore, stock that is shipped from one State to another or from one county to another may be subject to quarantine regulations, and there is always danger of introducing insects or diseases when plants are moved from one section to another.

SANITATION

Pathogenic organisms may be carried from one place to another on plants, plant parts, and soil. For this reason, soil should not be moved indiscriminately from one part of the nursery to another or from one nursery to another. Plows, harrows, and other tools should be thoroughly cleaned before they are moved from nursery to nursery. The same precautions should be observed within the nursery if it contains spots infested with *Verticillium* or other soil-borne pathogenic organisms. *Sclerotinia* may be spread in the nursery on diseased plants. Therefore, plants removed from the beds to prevent spread of disease should be burned.

MODIFICATION OF CULTURAL PRACTICES

The prevalence and severity of diseases are frequently influenced by cultural practices. As far as practical, disease-control methods are usually based upon modification of cultural practices.

SOIL PREPARATION

The tilth and drainage of the seedbed are important in the prevention and control of diseases. Low places in the beds tend to become waterlogged, and poor emergence and growth of seedlings result. High places dry out quickly, and poor germination may result because of lack of moisture. Plowing or other tillage operations when the soil is either too wet or too dry may break down the soil structure and cause poor drainage and aeration.

IRRIGATION

In order to obtain satisfactory germination of guayule seed in the nursery or in field seedings, the soil surface must be kept moist, but not excessively wet, for 7 to 14 days, depending upon the rate of emergence. After the seedlings have emerged the amount of water needed is contingent upon the demands of the plants rather than upon the evaporation of surface moisture. Excessive water during or after emergence may cause favorable conditions for damping-off and seedling root rot. Plants grown in soil maintained continuously at a relatively high moisture content usually develop large succulent tops, which provide ideal conditions for the growth of certain patho-

genic fungi. Abundant soil moisture is needed for the growth and spread of certain soil fungi. By keeping the soil moisture relatively low, many pathogenic fungi are held in check.

CULTIVATION

Guayule seedlings are more subject to pink rot if soil is piled against the lower leaves. Therefore, cultivation or other cultural practices that tend to throw earth against the plants should be kept at a minimum.

FERTILIZATION

Fertilizers are used in most nurseries in the production of guayule seedlings. Overfertilization, especially with nitrogen, should be avoided because nitrogen tends to increase damping-off losses. Furthermore, a dense ground cover of succulent vegetation favors the development and spread of diseases such as those caused by *Sclerotinia*.

DENSITY

Density in itself does not cause disease, but pathogenic fungi may spread from plant to plant more readily in dense stands. To facilitate disease control, stands should be of the proper density to assure plants of desirable size and form but not dense enough to cause crowding and result in plants of low vigor. In guayule nurseries a density of approximately 25 plants per square foot is usually considered desirable.

WEEDS

Weedy land creates both cultural and disease-control problems. In regions where the annual rainfall is concentrated in the winter months the soil on nursery areas often becomes too wet for weed control. The plowing under of a luxuriant crop of weeds prior to seeding creates biotic conditions which may be deleterious to the emergence and growth of seedlings.

Weeds compete with the emerged seedlings for nutrients and light and thereby affect their growth rate and prolong the period in which damping-off may occur. Seedlings shaded by weeds become succulent and may be injured by sudden exposure to sunlight when the weeds are removed. Furthermore, weed-control operations often cause death or injury to many seedlings. Hand weeding may lead to considerable loss, especially when done by careless or improperly trained workers. The possibilities of loss are further increased by the density of the weed cover and the degree to which the seedlings are suppressed. Weed control by the use of oil sprays was extensively practiced in guayule nurseries;⁹ when properly applied such sprays gave good weed control and caused little damage to guayule. In general, the greater the number of weed-control operations required on a given area, whether hand weeding or oil-spray applications, the greater the cumulative damage to the seedlings.

FUNGICIDES

Guayule has been relatively free of foliage diseases both in the nursery and in field plantations. Under conditions of excessive moisture and crowding, the lower leaves of nursery plants have been attacked by *Sclerotinia* spp. and *Botrytis cinerea*. Control of these fungi was attempted by the use of fungicides, but other measures such as drying out the nursery beds

⁹ BENEDICT, H. M., and KROFCHEK, W. THE CONTROL OF WEEDS IN GUAYULE SEEDLINGS. [Unpublished manuscript.]

proved more practical and effectively checked the diseases. A leaf spot of minor importance at the San Mateo nursery was successfully controlled on an experimental basis by the application of 6-6-100 bordeaux.

The tolerance of guayule to a number of fungicidal sprays has been tested. Lange (8) reported that guayule nursery seedlings were not injured by either 6-6-100 or 10-10-100 bordeaux. Experimental trials have shown that the dosages recommended by the manufacturers of the following readily obtainable fungicides did not injure guayule foliage: Yellow Cuprocide (cuprous oxide), and Kolofog (bentonite-sulfur).

In case a foliage disease that requires spraying occurs, 6-6-100 bordeaux is recommended for small seedlings and 6-6-100 or 8-8-100 for larger plants. In the preparation of 6-6-100 bordeaux 6 pounds of copper sulfate is dissolved in approximately 75 gallons of water in a 100-gallon spray tank. Six pounds of hydrated spray lime is stirred into a pailful of water, and the mixture is added slowly to the copper sulfate solution in the tank with the agitator running. Finally, water to bring the mixture up to the 100-gallon mark is added.

NURSERY DISEASES

DAMPING-OFF

"Damping-off" is a general term which in common usage includes pre-emergence damping-off (seed rotting in the soil and failure of germinated seed to emerge) and postemergence damping-off (seedling damping-off). Damping-off may be caused by a number of fungi. However, in any one location and at a given time usually one fungus is mainly, if not entirely, responsible for the losses occurring. The common fungi associated with damping-off in guayule are species of *Pythium*, *Phytophthora*, *Rhizoctonia*, and *Fusarium*.

ECONOMIC IMPORTANCE

Preemergence loss is not as obvious as postemergence, and frequently low emergence is attributed to causes other than pathogenic ones. In the field it is usually difficult to determine the reason for low emergence even though the cause may be suspected. If emergence is lower than expected from germination tests and the rate of seeding, pathogenic troubles should be suspected.

Preemergence loss is unpredictable because of its association with contributing factors. Greenhouse tests with soil from 3 Salinas nurseries and the results of nursery seedings indicated that 15 to 60 seedlings emerged from 80 viable seeds sown per square foot. Losses from preemergence damping-off vary from year to year and may be expected to differ with soil type, temperature, and other factors; therefore, control measures should be considered as a form of insurance. The organisms causing damping-off are found wherever crops are grown, and losses will occur when predisposing or contributing factors are favorable for the disease.

Loss from postemergence damping-off was low in the Salinas nurseries in 1943. Its occurrence was scattered, and its recognition was complicated by damage from oil spray used for weed control. These observations do not mean that heavy losses from damping-off may not occur, if conditions are favorable for damping-off fungi to develop while the seedlings are in the susceptible stage. This is borne out by losses which occurred in some of the field seedings in 1943 and 1944. In these cases loss was associated with excessive soil moisture.

SYMPTOMS

Poor emergence, rotting of nongerminated seed, and rotting of the roots and hypocotyls of germinated seed which fail to emerge or which are emerging characterize preemergence damping-off. The sudden wilting or collapse of seedlings in the cotyledon stage or before three or four leaves develop is the usual symptom of postemergence damping-off. The causal fungus may attack the plants at the soil line, or it may gain entrance through roots and progress upward into the bases of the stems. Usually the affected plants live but a short time after the symptoms are observed. However, in some cases where the wilting is caused by fungi present in the roots, apparent recovery may occur for a day or two before final collapse.

CONTROL

In 1942 and 1943 when the guayule nurseries were in full operation in California the prevailing practice was to sow hypochlorite-treated seed that had been pregerminated or kept moist for several days. Although sodium hypochlorite effectively sterilized the surface of the seed, it did not give protection against soil organisms.

If either threshed or unthreshed, dry, hypochlorite-treated seed is used, dusting before sowing with one of the several commercial fungicides used for seed treatment offers the best and cheapest form of control of preemergence damp-off. Sleeth⁷ demonstrated that of the various seed protectants Arasan (tetramethyl thiuram disulfide) and Spergon (tetrachloro-*para*-benzoquinone) give excellent results when used at the rate of 1 pound to 100 pounds of dry seed. These seed protectants have also given satisfactory results when used with threshed seed not previously treated with sodium hypochlorite. Hypochlorite-treated seed that is to be pregerminated should not be dusted with any of the common seed protectants because injury may result during germination.

Concentrations greater than 1 percent should be avoided and for general field use dosages of 0.75 to 1 percent are suggested. If these materials are not available and other seed protectants are, it is suggested that the dosages recommended by the manufacturer for similar seeds be used. Sufficient seed for a few beds should be treated to test the effectiveness of the fungicides before a large amount of seed is treated. The dosage can be adjusted for later sowing if a change seems advisable.

For maximum protection each seed must have a uniform covering of the protectant material. A rotary-type seed treater, which can be constructed from a metal drum, gives good results. Baffles should be placed on the inside of the drum, or the drum should be mounted off-center so as to rotate eccentrically, in order to coat the seed uniformly. Batches of seed are placed in the mixer, and the fungicide is added. The container should never be more than half full of seed and should be slowly rotated for 10 to 20 minutes.

Caution should be exercised in handling seed-treating materials, and all seed should be treated in a closed container. Such materials should be considered toxic; the fumes and dust should not be inhaled. If accidentally spilled on the skin, the material should be removed immediately by washing. The manufacturers' advice on the use and handling of these materials should be strictly followed at all times. Material should be stored out of reach of children and animals.

⁷ SLEETH, B. PRE-EMERGENCE LOSSES AND SEEDLING ROOT ROT AND THEIR CONTROL IN GUAYULE NURSERIES. U. S. Bur. Plant Indus., Soils, and Agr. Engin., Plant Dis. Rptr. 28: 954-955. 1944. [Processed.]

Postemergence damping-off is difficult to control. Usually the disease appears suddenly and progresses rapidly, and by the time it is observed the damage is so extensive that saving of the few remaining plants in an infection center is not worth the necessary effort. If the disease appears to be spreading from an infection center, the spread may be stopped by drenching the plants and soil surface with a fungicide such as Semesan or Thiosan in a band or zone a few feet wide just in advance of the disease.

Control of postemergence damping-off in vegetable and tree seedlings by the application of fungicides to the bed surfaces has given excellent results in some instances and disappointing ones in others. When an outbreak occurs it is suggested that whatever promising material is at hand be used experimentally. The manufacturer's directions on such commercial products as Semesan and Thiosan should be strictly followed. (See warning, p. 9.)

As in the case of many other troubles prevention is easier and cheaper than control after a disease appears. Postemergence damping-off is generally associated with excessively moist conditions, and losses can be largely avoided by careful watering. The seedlings should have sufficient water to maintain good growth, but water in excess of this requirement must be considered as a predisposing disease factor.

Damping-off is frequently associated with soils high in organic matter or nitrogen. The organic matter provides an excellent place for pathogenic organisms to grow and build up a large population. Nitrogen may stimulate succulent plant growth, which is more susceptible to fungus attack.

SEEDLING ROOT ROT

SYMPTOMS AND PREDISPOSING FACTORS

The roots of young guayule seedlings are frequently attacked by *Pythium ultimum*, which causes a root rot (4). Stunted seedlings with purplish cotyledons are often the first indication of root rot. Both the taproot and the lateral roots may be attacked, and the symptoms of the disease will depend upon the amount of root system destroyed by the fungus (fig. 1). Plants that have their roots destroyed near the soil surface usually die; those that are attacked deeper may be stunted but eventually recover. Many plants have only a few roots affected and do not show any above-ground symptoms of disease. Plants that recover from root rot may have multiple or twin taproots which make them difficult to handle in the planting machines.

Excessive moisture is probably the most important single factor contributing to seedling root rot, but temperature may be important also. During the spring and early summer of 1943, cool weather retarded germination and the irrigation schedule normally needed to obtain emergence in a week or 10 days was maintained for a much longer period and excessively high soil moisture resulted in certain blocks. In those blocks in which a saturated condition was reached, 50 to 75 percent of the seedlings were affected by root rot. Fewer infected plants were found in blocks having a lower soil-moisture content.

CONTROL

Regulation of watering so as to avoid excessively high soil moisture is the only practical control for seedling root rot.

SPLASH INJURY

OCCURRENCE, SYMPTOMS, AND CAUSE

In the guayule nurseries irrigation was provided by overhead sprinklers

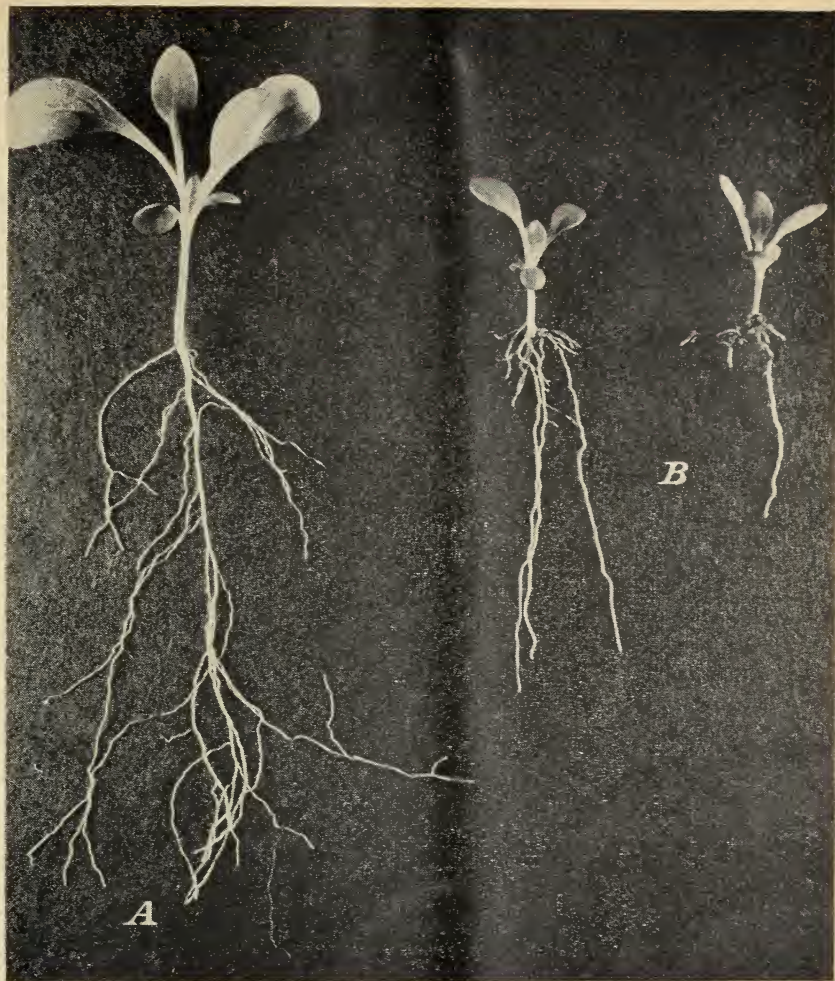


FIGURE 1.—A, Healthy guayule seedling; B, seedlings affected with a root rot caused by *Pythium ultimum*.

such as are commonly used in forest-tree nurseries. This system sprays water into the air and may cause considerable splashing of the soil, depending upon the size of the water droplets, wind velocity, and soil type. Injury to guayule seedlings during the period immediately after emergence and until the plants were 4 to 6 weeks old was associated with splashing of soil particles on the leaves and cotyledons. Injury of this nature in the California nurseries has been referred to as splash injury, or soil-splash injury. Splash injury was generally distributed throughout the nurseries, and occasionally it caused severe loss particularly in combination with damage from oil spray used for weed control.

The first evidence of injury is a drying of the margins of the cotyledons and leaves, usually commencing at the tips and gradually progressing toward the bases and into the stem. The necrotic areas vary from light to dark

brown. The leaves and cotyledons of severely affected seedlings are frequently brown and shriveled, but the root crown and roots are apparently healthy. Later the roots die and are invaded by saprophytic fungi. The young leaves and cotyledons are generally covered with small soil particles, and the stem may or may not have an encrusting collar of soil and sand. The presence of soil on the leaves, however, does not always lead to splash injury. Injury may be confined to a few slightly affected seedlings in a bed, or it may be extensive and severe enough to kill all the plants in a considerable area. Symptoms similar to those found in guayule have also been observed in weed seedlings.

When splash injury first appeared in the guayule nurseries attempts to isolate organisms from the affected plants yielded only fungi generally considered as saprophytes. Examination of free-hand sections of leaves or cotyledons under the microscope failed to demonstrate mycelium in the affected tissues. Addicott (1) made a systematic histological study of splash-injured plants and showed that the cells in injured portions of the plants were plasmolyzed and that the number of such cells increased with the degree of injury. He was unable to find any evidence of micro-organisms in the affected tissues.

Several explanations have been offered as to the cause of splash injury. These include injury to the cotyledons and leaves by actual rupturing of the plant cells by small particles of soil; the presence of some soluble toxic material in the soil; and dehydration, smothering, or some physiological disturbance brought about by the soil layer on the leaves.

From greenhouse experiments and observations in the nurseries Sleeth⁸ concluded that in many instances splash injury may be caused by a concentration of soluble salts either in the soil or on the surface of the soil-splashed plants. These salts accumulate at or near the soil surface from frequent light irrigations during the period when the seed is germinating. After germination the alternate splashing and drying tend to concentrate these salts on the tender leaves and cotyledons and cause plasmolysis. A toxic action may also occur from the absorption of excess salts through the roots of the plant or from soil splashed on the cotyledons and leaves. In some cases both forms of injury probably occur.

The relation of water pressure to the occurrence of splash injury has been commonly observed. The greatest loss usually occurs on areas where large drops of water strike the soil with considerable force. Low water pressure produces large drops, and soil splash is often serious at the ends of the irrigation lines where the pressure is lowest. Splash injury may be related to the vigor of the seedlings. A healthy, vigorous seedling is less likely to succumb to soil splash than one weakened by nematodes, fungi, insects, or poor growing conditions.

CONTROL

Satisfactory control of soil splash has been obtained by modifying the sprinkler system to avoid excessive splashing. This has usually been accomplished by increasing the pressure in the sprinkler lines, by reducing the load on the pumps, or by changing the size of pipe and fittings. In case wind increases splashing, watering should be confined to the calm, early-morning hours.

⁸ SLEETH, B. A SOIL-SPLASH EXPERIMENT. Special Guayule Research Project Rpt. 1943. [Unpublished.]

At the Bakersfield nursery control of soil splash was effected by withholding irrigation after emergence until the seedlings were large enough to be uninjured by splashing. Ordinarily, water can be withheld for several weeks without injury to young seedlings if a sufficient supply has been stored in the soil during or prior to germination. The water requirement of young seedlings is relatively low, and newly emerged seedlings remove but a small amount from the soil over a period of several weeks.

HEAT INJURY

Heat injury has been observed in both nursery and field seedlings. Seedlings which have just emerged and small plants a few days old are commonly affected. The symptoms are progressive drying and browning of the leaves and cotyledons downward to the soil surface. The roots of recently killed plants usually appear normal. Heat injury generally develops suddenly and progresses rapidly until most of the seedlings are killed. In the nursery heat injury may be confused with splash injury.

Newly emerged seedlings and small plants with two or three leaves are intolerant of high soil temperatures, and successful stands are difficult to obtain when maximum air temperatures rise above 90° F. Heat injury has been of infrequent occurrence at Salinas, Calif. However, considerable loss of newly emerged seedlings has resulted from heat injury in the nurseries near Indio, Calif., and Phoenix, Ariz. Field seedlings made during the summer near Edinburg, Tex., have also been affected.

OIL-SPRAY INJURY

Weeds in guayule nurseries and in field seedlings have been effectively and economically controlled by oil spray. The value of oil spray for weed control depends upon its selective action. Oil is very toxic to certain weeds and less toxic to guayule, but under certain conditions it may severely damage or kill the latter. The oil used in the spray consisted of 25 percent Diesel oil and 75 percent stove oil. This was mixed with water at the rate of 1 gallon of oil to 4 gallons of water. Ordinarily, 6 gallons of this mixture containing 1.2 gallons of oil was used per 400-foot nursery bed (1,600 square feet).

Injury from oil spray is sometimes difficult to distinguish from other types of seedling injury, particularly splash injury. Oil injury usually becomes apparent within a day or two after oil is applied, and it may result in a sharp increase in the number of dead seedlings. On the other hand, splash injury develops gradually and continues for a period of several days.

PINK ROT

ECONOMIC IMPORTANCE

A root rot caused by *Pythium ultimum* and commonly referred to as pink rot was prevalent on plants from 6 to 16 weeks old in the Salinas nurseries during June, July, and August (4). It was also present in the southern California nurseries and at Bakersfield. Pink rot losses were unevenly distributed throughout the nurseries. In general, the average loss throughout the season was less than 1 percent. Individual plants were attacked, and there was little evidence of spread from diseased to healthy plants. Many areas in which the disease caused damage in 1942 had practically no loss in 1943.

SYMPTOMS

Plants affected with pink rot wilt suddenly during the warm part of the day (fig. 2, *A*). Root lesions are usually limited in longitudinal extent (fig. 2, *C*). At first the diseased bark is translucent and pinkish; later the cells collapse, turn reddish or brownish, and slough off when the plant is pulled. The wood is stained pink or red at the lesion and for a short distance above and below it. The pink or red discoloration of the wood is very pronounced when the plants are freshly pulled, but it disappears on exposure to the air or drying in the soil.

Root lesions occur most frequently on the taproot at depths of 2 to 6 inches. Sudden wilting and death of the plants are generally associated with lesions on the upper portion of the taproot. If the lesions are lower on the roots, the affected plants wilt but generally recover by the formation of lateral roots above the diseased portion of the taproot.

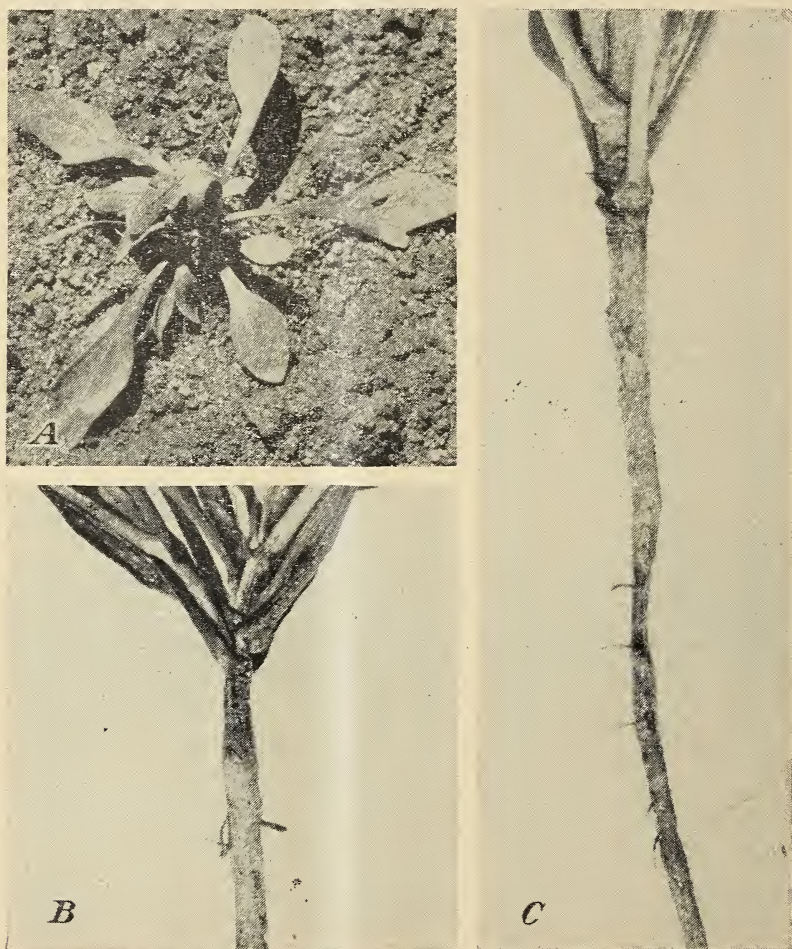


FIGURE 2.—*A*, An 8-week-old guayule plant which wilted because of a pink rot lesion on the root; *B*, plant with a lesion at the root crown; *C*, seedling with a root lesion approximately 3 inches below the soil surface.

In several areas in the Alisal nursery the taproots of freshly pulled plants exhibited numerous red or pinkish cracks. These varied from those circular in shape and barely perceptible to the naked eye to elongated fissures from $\frac{1}{8}$ to $\frac{1}{4}$ inch long. Most of these cracks were confined to the bark and caused no apparent injury to the plant; others were associated with typical pink rot lesions. These cracks have been regarded as growth cracks which, if deep enough, may provide entrance points for the fungus causing pink rot. They were usually most noticeable on the roots several days after irrigation.

Lesions on the lower stem or at the root crown were commonly associated with partial burial of the stem and lower leaves (fig. 2, B). Dissection of a number of plants with crown lesions revealed that the fungus had entered through dead cotyledons or lower leaves and had followed the branch trace into the central cylinder where the characteristic pink rot developed. The first indication of crown lesions on older seedlings was the formation of a "flag," or dead lower branch. This was followed by wilting and death of the plant.

PREDISPOSING FACTORS

In the Salinas nurseries pink rot was associated with excessive irrigation on heavy soils, cultivation, or other cultural practices that pile earth against the plants, and prolonged periods of either foggy weather or high humidity.

A number of blocks on poorly drained soil at the Santa Rita nursery were watered for 4 hours with the overhead sprinklers on July 2 and 3, 1942, and waterlogging of the soil resulted. Pink rot developed 3 or 4 days later on the taproots at a uniform depth of 4 to 6 inches. Localized areas with numerous pink rot infections were also observed in the Alisal nursery in 1942 where water accumulated when the blocks were irrigated.

A number of plants from 12 to 16 weeks old died at the Santa Rita nursery in 1942 from a disease then termed "collar rot." The disease was characterized by sunken lesions at the root collar. Observations and isolations made in 1943 on similarly affected plants indicated that the condition was caused by *Pythium ultimum* and was a form of pink rot. The disease ran its course in a few weeks and was associated with the banking of earth against the plant by cultivation.

In 1943 an outbreak of pink rot in the Alisal nursery followed deep furrowing by a machine used to apply fertilizer. The machine was operated when the soil was wet and piled earth against the plants. Within 10 days many plants died from crown lesions. Other less severe outbreaks in the Alisal nursery were traced to the use of the fertilizer machine or to cultivation. The number of seedlings with crown lesions was proportional to the depth to which soil was banked against the plants. The number of root lesions was not increased by cultivation. Density of stand appeared to be unrelated to the amount of pink rot, and plants in thin stands were as subject to attack as those in dense ones.

Crown lesions were more common during foggy weather at Salinas than during fog-free periods. The fog and resulting high humidity together with overhead irrigation maintained conditions near the surface of the soil favorable for the disease to develop. During periods of low humidity pink rot was restricted to the taproots deep in the soil.

CONTROL

Losses from pink rot may be largely prevented by avoiding excessive irri-

gation particularly on heavy soils, regulating irrigation so that water does not stand on the beds, and reducing to a minimum cultivation and other cultural practices that throw earth against the plants.

VERTICILLIUM WILT

SYMPTOMS

Guayule is susceptible to verticillium wilt, a common and widespread disease of cultivated orchard and crop plants, caused by a soil fungus,

Verticillium albo-atrum.

The first expressions of the disease in guayule seedlings are yellowing and curling of the older leaves and a brownish discoloration of the vascular tissues. In advanced stages of the disease the growth rate is sharply reduced and the affected seedlings exhibit symptoms of water deficiency. The degrees of wilt and of subsequent recovery depend upon the extent of injury to the vascular tissues. Severely affected plants die; those less severely affected may recover and resume growth or remain alive without making appreciable growth. Field identification of off-color or stunted plants as wilt-diseased is dependent upon the presence of brownish streaks in the wood. These brownish streaks are most pronounced in the lower stem and are seen to best advantage by splitting the plant longitudinally (fig. 3, B).

PREDISPOSING FACTORS

Although the presence of the causal fungus, *Verticillium albo-atrum*, in the soil is necessary for the disease to develop, the time of its appearance and the degree

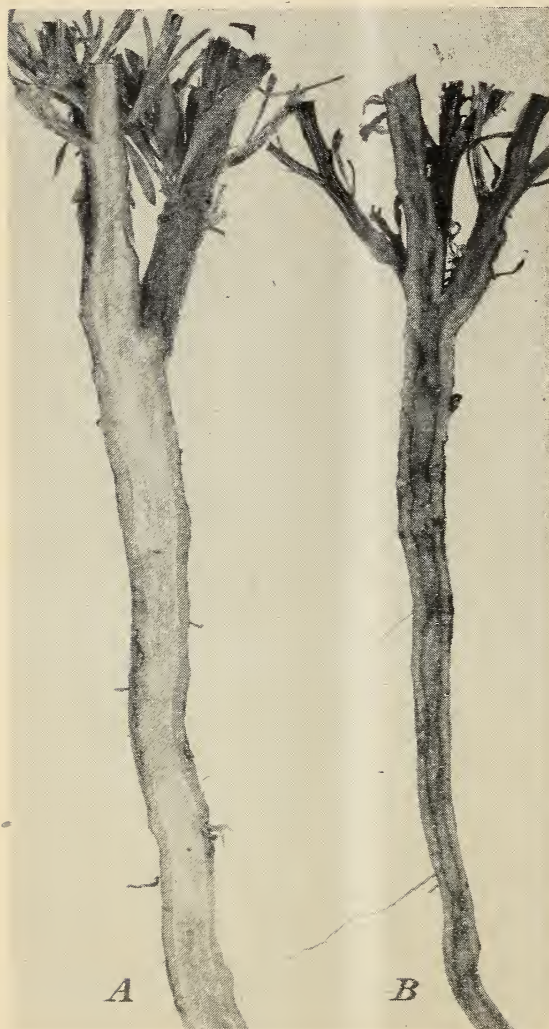


FIGURE 3.—A, Section of a healthy guayule transplant showing the normal color of the bark and wood after approximately 6 months in the field. B, Section of a transplant of the same age severely affected with verticillium wilt. The woody portion of the root and stem was light to dark brown.

of damage to diseased plants are associated with stand density, moisture, temperature, and soil fertility. The ability of an infected plant to outgrow the disease depends upon the maintenance of good growing conditions. If new vessels are formed faster than existing ones are damaged by the spread of the fungus in the cells, continued growth is possible without the stunting and wilting usually associated with the disease. High stand density and low fertility are particularly conducive to severe disease symptoms.

CONTROL

Land infested with *Verticillium* should be avoided for nurseries. Since the presence of the fungus in the soil is difficult to detect, land long planted to susceptible crops such as cotton and tomatoes should be considered with suspicion. If *Verticillium* is present in portions of the nursery, these areas should not be used for the production of stock.

Verticillium remains viable in the soil for an indefinite period, and it may be expected to increase in soils that are continually planted to a susceptible crop such as guayule. Clean land may be infested by the introduction of contaminated soil, diseased plant parts, or planting stock. Precautions should be exercised, therefore, to avoid moving soil or diseased plant material from infested to clean areas on machines or by the movement of irrigation water.

SCLEROTINIA ROT

ECONOMIC IMPORTANCE

Of the various pathogenic fungi attacking guayule, *Sclerotinia sclerotiorum* and *S. minor* caused the greatest loss of plantable seedlings in the Salinas nurseries in 1942 and 1943. These same fungi also destroyed many plants in storage (p. 25) during this period. Both *S. sclerotiorum* and *S. minor* cause disease of lettuce, beans, and other plants; their presence in the guayule nurseries was related to past infections on susceptible crops.

SYMPTOMS

Plants affected with sclerotinia rot are characterized by a soft, watery, odorless rot of the root and stem tissues. Under humid conditions, tufts of white cottony mycelium develop on the diseased plants. Later sclerotia develop from these white tufts (fig. 4, A). White mycelium may also be produced on the soil surface and on dead leaves of infected plants. This mycelium is difficult to detect when dry, and the only evidence of the disease on plants that have been dead for some time is the presence of sclerotia on the surface or within the tissues or a light-brown shredded top (fig. 5, C).

LIFE HISTORIES OF CAUSAL FUNGI

Both *Sclerotinia minor* and *S. sclerotiorum* produce black, irregular-shaped bodies called sclerotia on the surface or in the tissues of diseased plants (fig. 5, E and F). These sclerotia keep the fungi alive in a dormant state during periods unfavorable for vegetative growth.

The sclerotia of *Sclerotinia sclerotiorum* produce apothecia, which develop as small, cup-shaped fruiting bodies on the surface of the ground provided abundant moisture is present and the temperatures average between 60° and 70° F. (fig. 5, A). These are connected to the sclerotia by slender stipes, the length of which depend upon the depth of the sclerotia in the soil. The apothecia, which range from $\frac{1}{4}$ to $\frac{1}{2}$ inch in diameter when fully expanded, are creamy white or flesh-colored when newly developed but become darker with age. Ascospores, which may be carried for some distance by the wind,



FIGURE 4.—Diseased guayule plants showing white, cottony tufts of mycelium of *Sclerotinia sclerotiorum* (A) and tufts of gray mold, characteristic of *Botrytis cinerea* (B).

are discharged forcibly into the air from the apothecia. If the ascospores fall on dead leaves or other dead organic material and moisture is present, they germinate and develop a white mycelium capable of attacking healthy tissue.

Sclerotinia minor differs from *S. sclerotiorum* in that it seldom forms apothecia (fig. 5, B) and usually produces mycelial growth directly from the sclerotia.



FIGURE 5.—A and B, Apothecia of *Sclerotinia sclerotiorum* (A) and *S. minor* (B). C, Nursery seedling of guayule killed by *S. sclerotiorum*. Note the shredded top, which is typical of sclerotinia rot. D, Root lesion caused by *S. minor* on a field-grown plant. E and F, Sclerotia of *S. minor* (E) and *S. sclerotiorum* (F).

MODE OF INFECTION

Sclerotinia sclerotiorum may infect guayule seedlings either by means of mycelium growing in the soil or by ascospores. The relative importance of the two methods of infection in the development of the disease is dependent upon moisture and temperature as well as upon size and vegetative condition of the seedlings. At Salinas ascospore infections were common in August and September when moisture was supplied by irrigation and during the rainy period in late winter and early spring. Direct infection by mycelium growing in the soil has been observed in August. However, this mode of infection is probably more common in late fall after light rains have provided sufficient moisture for the growth of mycelium. The development of the soil mycelium is checked and possibly entirely stopped by drying.

Sclerotinia minor infections originate from soil mycelium which directly attacks the roots of seedlings or grows to the surface and develops saprophytically on dead leaves and other organic material before coming in contact with the leaves or tops of the guayule plants.

CONTROL

As sclerotinia rot is caused by soil fungi, the best control measure is to avoid infested land. Land on which lettuce or other susceptible crops have been grown should be accepted for nursery sites only if other land is not available. A survey to determine the sclerotial population is suggested if there is any question as to the potential hazard from the disease.

If *Sclerotinia* is already present, control may be obtained by preventing conditions favorable for the fungus to develop. Specific recommendations follow:

- (1) Reduce to a minimum the amount of water applied to blocks reaching the closed-canopy stage and irrigate in the morning. This will permit the ground and plants to dry out in the afternoon when the sun is bright.

- (2) Harden plants by withholding water as soon as they reach plantable size, or better still grow plants with a limited supply of water in order to prevent large succulent tops.

- (3) Pull out all diseased plants and enough of the neighboring plants to form holes in the plant canopy, which will permit the soil to dry out and check the mycelial growth of the fungus. The diseased plants should be burned so as to destroy any sclerotia on the surface or buried in the tissues.

BOTRYTIS ROT

SYMPTOMS AND PREDISPOSING FACTORS

Botrytis rot is caused by the fungus *Botrytis cinerea*, which is ordinarily a saprophyte on dead leaves or other dead organic matter and attacks living guayule plants only when conditions are extremely favorable. The fungus attacks the dead or nearly dead lower leaves first and spreads to the stems, causing a soft rot. The diseased tissues are soon covered by a gray mold, which is the fruiting stage of the fungus (fig. 4, B).

Plants dug and packed in the nursery during the rainy period, when *Botrytis* was fruiting on diseased ones and on dead organic material, were covered with spores of the fungus. When sufficient moisture was present in the crates, these spores germinated and the resulting mycelium attacked the plants and caused a soft rot. Affected plants could be readily recognized by the gray mold which covered the diseased tissues.

In February and March 1943 *Botrytis* attacked topped plants that had been left in the beds and caused a soft watery rot. Many plants were killed. The tops of others died back to the ground, but later they sprouted from the root crowns.

Plants which have developed large succulent tops are susceptible to attack by the fungus during foggy or rainy weather or when abundant moisture is present from irrigations. Rots caused by *Botrytis* and *Sclerotinia* develop under similar conditions and are frequently present in the same areas in the nurseries.

CONTROL

Botrytis rot is readily prevented in the nursery by avoiding excess watering and other practices that produce plants with tall, succulent tops. Once the disease develops, it can be checked by drying out the beds in the manner recommended for *sclerotinia* rot (p. 20).

ROOT ROTS

SYMPTOMS AND ECONOMIC IMPORTANCE

The term "root rot" refers to a condition in which the taproots and laterals of nursery stock die and rot at some point below the root crown. Root rots may be caused by pathogenic fungi or may result from drowning.

Root rots were more common in the Salinas nurseries in 1942 than in 1943. The nurseries were hurriedly constructed in 1942, and seeding took place after hasty ground preparation in many instances. This resulted in a number of low places where water accumulated and in areas with compacted soil layers that were impervious to water. In 1942, when the general practice was to irrigate heavily, excessive water in low areas and in those with poor drainage resulted. In these poorly drained areas the plants gradually died. Many of the dead plants had root lesions characterized by black sunken tissue from which a species of *Phytophthora* was isolated occasionally.

Approximately one-third of the seedlings grown in the nursery of the Intercontinental Rubber Co. at Salinas in 1941 were unfit for planting in the spring of 1942 because of root rot. This rot affected the roots at depths ranging from 1 to 7 inches. When the areas where the root rot occurred were compared with the soil map, it was evident that the disease was most severe on the poorly drained soils. In a small portion of the nursery devoted to an experimental plot in 1942, the water table rose to within 3 inches of the surface during February and March 1943. Practically all of the plants were affected by root rot. Rot of this type was attributed to drowning, and many plants recovered by the formation of new roots when the water table receded.

CONTROL

Root rot, whether caused by a fungus or associated with drowning, is related to excessive soil moisture; it is apparent that control consists in avoiding saturated soil.

LEAF DISEASES

Leaf spots were observed in the nurseries at Salinas and near Oceanside, Calif. The diseases were characterized by definite, circular, blackish spots of varying size on the leaf blade. These spots frequently coalesced and formed irregular patches. They developed mainly on succulent plants in areas that received an excessive amount of water.

Isolation attempts yielded a bacterium from diseased leaves at the San Mateo⁹ nursery in the Oceanside district and a saprophytic fungus from those at the Salinas nurseries. At the San Mateo nursery control was obtained experimentally with 6-6-100 bordeaux.

Leaf spots have not caused sufficient damage, however, to warrant spray applications in the nurseries; the best preventive treatment is to avoid overwatering or other cultural practices that keep the plants excessively succulent.

DEFICIENCY DISEASES

An adequate supply of the elements needed for plant nutrition is as essential to guayule as to other crop plants. Chlorosis, or a yellowing, of the foliage caused by a nitrogen deficiency was common in the Alisal nursery in 1943, particularly on the sandy soils. The factors which contributed to nitrogen deficiency were leaching by frequent irrigations and growing too many plants on a given area. Marked improvement in the color of the plants followed applications of ammonium sulfate or sodium nitrate. These fertilizers, which are readily soluble in water, were applied dry and the area was immediately irrigated. Insufficient amounts of other essential elements may also cause deficiency diseases, but so far chlorosis caused by lack of nitrogen has been the only one recognized in the Salinas nurseries.

INJURY ASSOCIATED WITH HARDENING

The common nursery procedure has been to grow guayule seedlings with a plentiful supply of water. When the plants were large enough for planting in the field, they were hardened by gradually reducing the frequency and length of irrigations.

The amount of water applied during the growing season, the nature of the soil, and the density of the stands have a marked influence on the type of seedlings produced. Excessive watering of plants on sandy soils, particularly if the stands were dense and fertilizers were used, often resulted in plants with tall, succulent tops.

Hardening plants with succulent, leafy tops, even though the water was gradually reduced, usually resulted in severe drought symptoms. The plants wilted and the leaves curled. After several weeks of drying only a few functional leaves remained on the tops. Later, after periods of rainy weather, plants died in groups, generally in the interior bands in the beds and often for a distance of several feet in a band. Isolations from the tops of dead plants and from those with lesions at the surface of the ground yielded saprophytic fungi or those considered as weak parasites.

STORAGE DISEASES

PREPARATION OF STOCK FOR SHIPMENT AND STORAGE

Under the system of guayule culture employed in 1942 and 1943, seedlings were grown for one season in a nursery before they were transplanted to the field. The areas to be planted were often located at considerable distances from the nurseries, and stock was frequently in transit several days. Regardless of how closely nursery digging and field planting were coordinated, variations in weather conditions at widely separated points often disrupted

⁹ LOCKE, S. B. PATHOLOGICAL ACTIVITIES, OCEANSIDE AND INDIO NURSERIES. *Special Guayule Research Project Rpt.* 1943. [Unpublished.]

scheduled operations. As a result crates of stock accumulated and were stored until weather or other conditions were suitable for field operations.

In shipping plants by rail or truck it is usually necessary to conserve space by crowding the crates. This reduces ventilation and may lead to heating, especially in the interior of the stack. At the same time those on the outside, if exposed to free air movement, may dry excessively. The danger from unfavorable conditions encountered in shipping increases with the time required to move stock from the nursery to the field. Shipping plants short distances requires no special precautions, but long-distance rail or truck shipments may demand considerable care in packing if the stock is to reach its destination in a plantable condition. Satisfactory methods of packing guayule seedlings for shipment to the planting areas or for storage were developed through experience and by experimentation.¹⁰

After the seedlings had reached a desirable size and had been properly hardened, they were topped to within 2 or 3 inches of the ground and undercut so as to leave a taproot 5 to 6 inches long. The plants were pulled by hand and graded as to size. The grading standards varied from season to season, but in general plants selected for field use ranged from 5/32 to 16/32 of an inch in diameter at the root crown and were free of large lateral roots, which would interfere with the operation of the planting machines. The sorting crews were instructed to eliminate dead leaves, dead or diseased plants, and loose earth adhering to the roots.

The graded plants, 3,000 to 5,000 per crate, were packed in alternating layers in lettuce crates whose inside dimensions were approximately 22 by 17½ by 13½ inches. By this arrangement the tops were on opposite sides of the crates with the roots toward the center. Waxed paper was used on 6 sides of the crates during dry weather and on 4 sides during the rainy season, in order to protect the seedlings from desiccation. Shingletow or a mixture of shingletow and sphagnum moss was commonly used to insulate the plants from one another. If the seedlings were crated for immediate use, paper separators were employed instead of packing material. These are necessary for efficient handling of the plants on the planting machine. The plants were firmly packed to reduce shrinkage and consequent disarrangement in shipping.

FACTORS INFLUENCING THE DEVELOPMENT OF DISEASES

MOISTURE

Fungi that cause storage diseases may be introduced into a packed crate either as spores on the surface of healthy or diseased plants or as mycelium in the tissues of infected plants. Control of molds and diseases in crated plants is greatly facilitated by regulating the amount of moisture on the tops and roots of the seedlings when packed, the moisture content of the packing material, and the number of sides of the crate protected by waxed paper.

Free moisture on the surface of the plants is ideal for the development of fungi. During periods of low humidity regulation of the amount of moisture on the top and roots is relatively simple. The only precaution needed is to delay digging in the mornings until the tops are dry. If irrigation is necessary to soften the ground for digging, sufficient time should

¹⁰ ERICKSON, L. C., and SMITH, P. F. TRANSPLANTING GUAYULE NURSERY PLANTS. [Unpublished manuscript.]

elapse between the application of the water and the lifting of the stock to permit the surface of the plants to dry thoroughly.

After the winter rains start, the plants are frequently wet for days at a time by rain or fog. Humidities are high and the tops do not dry readily. During the rainy season it is often impossible to dry the plants sufficiently for long storage periods and stock should be planted as soon as dug or held for only a short time in cold storage.

The desirable moisture content of the packing material will depend both upon the moisture content of the plants and upon storage conditions. During the winter months, when the plants contain considerable moisture and water loss from the crates is relatively low because of high humidity, the packing material should not contain over 50 percent moisture on a dry-weight basis. When humidities are low it may be desirable to add moisture to the plants; therefore, the packing material may be adjusted to from 50 to 70 percent moisture. Under no conditions should packing material be used with over 100 percent moisture on a dry-weight basis because of the danger from heating and disease.

Evaporation of moisture from the packed seedlings may be regulated by lining the crates with waxed paper. Under conditions of low humidity, complete coverage on six sides is needed for maximum protection from desiccation. During the rainy season, when the plants themselves contain more moisture and the humidity is high, paper on four sides is recommended because it may be desirable to lose moisture from the crate and plants rather than to conserve it.

Under storage conditions of fluctuating temperatures, moisture may collect on the inside of the waxed-paper linings. If the stock is to be planted within a few days this condensation should cause no concern, but for plants held in storage it may lead to molding and serious disease loss.

TEMPERATURE

The length of time that plants may be held in crates without danger of disease and heating depends largely upon the storage temperatures. Both common and cold storage are used in handling guayule planting stock.

For common storage a room, shed, or some other well-ventilated shelter which maintains the lowest possible uniform temperature throughout the day should be selected. The length of time that plants may be held in common storage should be determined by examination of the plants at regular intervals. Experience indicates that plants packed during rainy periods should not be held longer than 5 days unless the temperatures are around 50° F. or lower. Plants dug during dry periods may be held much longer without danger of loss from disease.

For maximum control of storage diseases temperatures from 32° to 34° F. in a well-ventilated cold-storage room are required. The maximum length of time that guayule seedlings may be safely stored at these temperatures will depend upon the condition of the plants at the time they are placed in storage. Completely dormant, surface-dry plants that have lost most of their leaves may be stored for 4 weeks without danger from disease, and if properly protected against desiccation they may be held as long as 8 weeks without undue loss. Moist plants and those with green leaves deteriorate rapidly, and the disease hazard is increased to the point that cold storage at 32° to 34° is uncertain after 4 weeks. The safe storage period decreases as the temperature rises above 34°. As with common storage the factors that

determine the length of time plants may be held in cold storage are too complex to be stated for all situations. Therefore, crated stock in cold storage should be examined periodically and the safe storage period determined by the condition of the stock.

Crated stock should be so arranged in storage as to permit the air to circulate between the crates in order to dissipate the heat in the crates. If this is not done, the temperature of the plants in closely stacked crates may remain above storage temperatures for a week or 10 days after being placed in storage.

Proper ventilation of cold-storage rooms is desirable to prevent or reduce condensation of moisture within the crates.

HEAT INJURY

The amount of heat produced by plants in storage depends upon several factors. The physiological condition of the plants at the time they are packed is especially important. Very little heat is given off by dormant plants, but actively growing plants may produce sufficient heat to cause injury if they are confined for any length of time in a poorly ventilated box. However, dormant plants may start to grow and produce heat if stored at too high a temperature. Excessively wet packing material or the presence of wet leaves on the plants may also lead to heating from the action of fungi or bacteria.

Unhardened plants are particularly subject to heating in transit. In April 1943 untopped plants in an active growing condition were shipped in crates by express from Oceanside to Salinas. When received at Salinas 3 days later, the interior temperatures were very high and the plants steamed when the crates were opened. The tops and stems had blackened, and the plants in the interior layers had softened into a watery, sodden mass. Similar difficulty was experienced with other shipments of unhardened stock from Oceanside.

Heat injury usually manifests itself on the roots as water-soaked, discolored areas which may be limited in extent or may involve most of the roots. Heat-injured plants have little promise of survival. If storage or shipping conditions have been favorable at any time for heating, the plants should be carefully examined before being accepted for planting.

DISEASES CAUSED BY FUNGI

SUPERFICIAL MOLDS

The leaves and stems of guayule seedlings are covered with spores of various fungi. Some of these may grow under storage conditions and coat the leaves with fine, appressed, white molds. Many of these molds are confined entirely to the surface and do not attack the underlying tissue. Their presence indicates, however, that conditions were favorable for fungus growth; plants with superficial molds should be scrutinized for *Sclerotinia* and *Botrytis*, which cause disease under the same conditions.

SCLEROTINIA ROT

A soft storage rot caused by *Sclerotinia sclerotiorum* and *S. minor* was common and destructive in 1942 and 1943. The loss of stored guayule from sclerotinia rot was related to infections in the nurseries (p. 17) and to the season of the year when the plants were dug and packed.

Plants dug in the fall during the dry season were relatively free from disease under storage conditions. At that time very few diseased plants were

present in the beds to act as a source of inoculum, and plants packed under conditions of low humidity did not contain sufficient moisture for fungus growth. Nursery seedlings killed by *Sclerotinia* in late summer were readily detected in sorting, and, even though such plants were occasionally introduced into a pack, insufficient moisture was present for fungus growth.

After winter rains had provided moisture for the development of apothecia of *Sclerotinia sclerotiorum*, many seedlings were infected by ascospores. Incipient infections could not be detected in sorting, and plants in the initial stages of disease served as a source of inoculum. Humidities were high at this season of the year, and the surface of the plants was often moist when packed. Storage temperatures were frequently too high to check the growth of fungi, and the combination of suitable temperature and abundant moisture caused the rapid spread of *Sclerotinia* from infected plants.

Under storage conditions *Sclerotinia* develops a profuse, white, cottony mycelium on diseased plants, which spreads outward from the center of infection and attacks and rots other plants with which it comes in contact (fig. 4, *A*). This white mycelium frequently becomes very abundant and forms characteristic cottony tufts on the diseased tops and roots. Later these tufts become firm, whitish or grayish nodules, which turn into black, irregular-shaped sclerotia (fig. 5, *F*).

Groups of diseased plants, or nests, are usually conspicuous because of the white mycelium which binds them together. No spores are produced by *Sclerotinia* in a crate, and the only means of spread is by mycelium from plant to plant.

In case sclerotinia rot is present in crated stock, such stock should be carefully examined before planting. If only one or two small nests are present in a crate, the diseased plants and their neighbors may be culled with assurance that the remaining seedlings are reasonable risks for planting. However, if there are several nests or if these involve a considerable portion of the plants, the entire crate should be discarded.

BOTRYTIS ROT

Botrytis rot was almost as common and destructive as sclerotinia rot on stock held in storage in the spring of 1943. The spores of *Botrytis* are generally distributed in the nurseries and may be on the stems and leaves of seedlings when crated. Under favorable moisture conditions these spores germinate and produce mycelia which attack the packed plants and cause soft rot. Spore-bearing mycelium quickly develops on the diseased plants and produces spores by the millions. These may be scattered throughout the crate by moving or jarring and cause new centers of infection to develop.

Botrytis, like *Sclerotinia*, requires moisture for its development. It is most common on plants dug during rainy periods when the tops cannot be dried to a desirable moisture condition before packing. The fungus is checked by temperatures from 32° to 34° F. but develops readily near 40°.

Botrytis rot may be recognized by the gray fuzzy mold which grows on diseased plants (fig 4, *B*). All the plants in crates containing seedlings infected by *Botrytis* should be discarded. Even though many of the plants appear healthy, they are probably coated with spores or have incipient infections which may develop and kill the plants in the field.

CONTROL OF FUNGUS DISEASES

Practical control of storage diseases may be obtained by preventing or keeping to a minimum the introduction of diseased plants in crated stock,

packing surface-dry seedlings so that they do not lose or acquire additional moisture, and storing stock at low temperatures, preferably from 32° to 34° F.

PLANTATION DISEASES

EXTENT OF GUAYULE PLANTINGS

The history of guayule as a cultivated plant in the United States dates from 1912. During the 30-year period from 1912 to 1942, the Intercontinental Rubber Co. planted 8,000 acres of the shrub. This included 6,000 acres near Salinas, 500 acres in southern California, approximately 1,000 acres in Arizona, and the remainder in 53 small indicator plots distributed from California to Texas. In 1942 the Forest Service planted approximately 800 acres in the Salinas Valley, and by June 1944 it had planted more than 30,000 acres in widely scattered areas in California, Arizona, New Mexico, and Texas.

Considering the restricted geographic distribution of the early large-scale guayule plantings it is not surprising that few disease problems were encountered. Although many of the small indicator plots failed, it is impossible to determine from the records, except of five plots in Texas, whether diseases were present.

Information on the diseases of field-grown guayule herein reported is based upon observations on field plantings, experimental areas, and indicator plots located in California, Arizona, New Mexico, Texas, and Mexico and upon laboratory, greenhouse, and field experiments.

PREESTABLISHMENT LOSS AND PREDISPOSING FACTORS

In the spring of 1943 a systematic survey was made of 71 guayule fields in 3 planting districts in California to determine the causes and extent of preestablishment loss (failure of plants to grow after transplanting) and the presence of diseases that might ultimately affect the stand or yield. These fields had been planted from 3 to 6 months at the time of the survey. In each field a count of 2,000 plants was made in such manner that the effect of variations in soil type, drainage, and localized factors could in a general way be detected. Where local variations or disease caused appreciable differences in survival, additional counts were made to compare survival there with that of the remainder of the field. Survival by units ranged from 57 to 85 percent. In approximately one-fifth of the fields surveyed the survival was below 70 percent. In the course of the survey it was found that the causes of preestablishment loss could be classified as pathological, physiological, cultural, and environmental.

PATHOLOGICAL FACTORS

Transplanted guayule is frequently attacked by pathogenic fungi before it becomes established. Infections may originate in the nursery or in storage; however, the majority are believed to develop in the field after planting.

The conditions under which plants are stored and shipped are often particularly favorable for the development of several fungi which cause disease in the nurseries, notably *Botrytis* (p. 20) and two species of *Sclerotinia* (p. 17). If seedlings are already infected by these fungi when transplanted they probably will not survive. Uninfected seedlings coated with spores of *Botrytis* may survive if planted in dry weather, but they are poor risks if

planted during a cloudy or rainy period when the spores may germinate and cause infection.

Soil fungi commonly associated with preestablishment loss include species of *Fusarium*, *Pythium*, *Phytophthora*, and *Sclerotinia*. In addition, *Phymatotrichum omnivorum* has been observed to cause preestablishment loss in Texas and *Sclerotium rolsii* in Arizona. In some areas one or more of these organisms may be present in newly subjugated land, although they are generally more abundant in soil that has been cultivated for a number of years. The amount of loss depends upon the presence of pathogenic fungi, the condition of the stock, depth of planting, soil moisture, and temperature. Plantings made under temperature and moisture conditions conducive to immediate growth are the least subject to infection by fungi.

Fall planting has been practiced in many parts of California, but it has been found less desirable than planting in late winter or early spring. Seedlings planted in the fall are exposed to fungus attacks during periods when conditions are favorable for the development of certain fungi but unfavorable for the growth of the plants. In addition, transplants weakened by excessive drying, which under California conditions may occur in late fall or early winter, are particularly subject to fungus infection when moisture becomes available at a later date.

PHYSIOLOGICAL FACTORS

Transplanting disrupts for a time the normal processes of the plant inasmuch as its environment is changed and the greater part of the feeder roots are lost in digging or impaired by drying. Furthermore, the ability of a plant to survive transplanting depends to a considerable extent upon its physiological condition. Plants which have been stored for considerable periods do not resume growth as readily as stock planted immediately after digging or after only a short storage period and the survival is not as good.

Experience with unhardened or partially hardened nursery stock in 1943 and 1944 demonstrated the impracticability of using such plants under field conditions (7). Tests conducted at Salinas gave a survival of 12.5 percent for partially hardened stock from the Indio nursery and less than 1 percent for unhardened stock from the Oceanside nurseries. This stock was planted in May 1943 and was irrigated immediately. Insufficiently hardened plants are especially susceptible to damage in digging and planting, because of the tenderness of the plant parts. Cracks in the bark or other wounds occasioned by undercutting, digging, and packing provide points of entrance for disease-producing fungi.

CULTURAL PRACTICES

The amount of ground preparation necessary for a good planting job is determined by the type and moisture content of the soil at the time the field is prepared for planting. The heavier soils, such as clay, silty clay, and clay loam, are particularly difficult to prepare properly because of the tendency for clods to form. The size of the clods has considerable bearing on the manner in which soil packs around the roots of the plants. Large clods leave air spaces and subject the roots to drying. The lighter soils present less of a hazard in this respect because the finer material flows readily into the furrow made by the planter and is pressed more firmly around the plants by the packing wheels. In addition to providing conditions suitable for the proper firming of the plants in the soil, a well-prepared seedbed also results in more effective operation of the planting machine.

After the soil has settled in place the root crown of the transplanted seedlings should be at the soil surface or very near it. Plants that are planted so deep that the root crown and lower stem are covered are often subject to fungus attacks. Furthermore, if the plants are set too deep, sprouts which develop at the root crown must break through a layer of soil before reaching the surface. Because these sprouts are not adapted for pushing through the hard crust which frequently forms after rain or irrigation, preestablishment loss may result. Excessively shallow planting, on the other hand, exposes the roots to desiccation and serious loss results during hot, dry weather.

One of the most important factors preventing preestablishment loss is the providing of sufficient soil moisture to the plant. The transplant is without root hairs and has relatively few feeder roots; consequently, until new roots develop, absorption is dependent upon a much reduced root system which is poorly adapted to take in soil water. Satisfactory conditions for the growth of guayule transplants are readily obtained by irrigating immediately after planting. The furrows should be placed near the plants and sufficient water applied to firm the soil thoroughly against the roots. Such treatment greatly reduces the disease hazard by promoting immediate growth. In winter adequate firming of the soil is usually provided by rains.

Cultivation may contribute to preestablishment loss by disturbing or partially pulling the plants from the ground, by mechanically injuring the roots or crowns, or by covering the plants with earth. Frequently areas are found where all the plants in several rows have been cultivated out for some distance because of irregularities in the rows. Careless or unskilled tractor operators, excessive cultivator speed, and improperly spaced tools may greatly increase the amount of loss. Cultivation or irrigation operations before the plants have made sufficient growth to form clearly defined rows add to the hazards from cultivation loss. Consequently, much care should be exercised in these early operations in order to hold such losses to a minimum.

ENVIRONMENTAL FACTORS

Where dense patches of morning-glory (*Convolvulus arvensis* L.) or puncture vine (*Tribulus terrestris* L.) occur in guayule plantations the plants usually remain small and many eventually die. Unless these weeds are removed every week or two, they may absorb sufficient water to deprive the young guayule plants of the moisture necessary for growth. Oil sprays for weed control may be safely applied to dormant plants. However, severe injury may result if the spray is applied to plants with newly expanded leaves.

Preestablishment loss caused by a high surface concentration of soluble salts has been observed in an indicator plot and a nearby field plantation at Coalinga, Calif. In both places transplants failed to establish themselves in areas where the salt content was sufficiently high to form a white coating on the soil surface.

ROOT ROTS IN GENERAL

Root rots, in general, were associated with poor drainage caused either by the nature of the soil itself or by surface irregularities which permitted water to accumulate in limited areas. The mortality from root rot was greatest under irrigation on heavy soils or on those with clay pans or other impervious layers. Losses were also experienced on light soils especially at the beginnings and ends of the irrigation runs or at low places in the fields

where ponding occurred. Guayule is particularly intolerant of saturated soil during high temperatures and periods of active growth. During the season when guayule is dormant the soil may be saturated or nearly so for a considerable period without injury to the plants.

Most of the root rot losses in plantations in California have been caused by *Phytophthora drechsleri*; however, losses from bacterial rot have been severe in several plantings. Serious losses have been caused by *Phymatotrichum omnivorum* on experimental plantings in Texas. *Sclerotium bataticola* has also been found to attack plants in Texas, causing lesions at the ground line or just above. *Sclerotinia minor* and *S. sclerotiorum* have been observed to attack field-grown guayule in California and Arizona. Inoculation studies made in 1942 demonstrated that *Sclerotium rolfsii* was parasitic to guayule. A few plants killed by this fungus have been observed in a plantation near Chandler, Ariz., and also in a planting in Texas. Other fungi commonly isolated from root lesions are *Fusarium* spp. and *Rhizoctonia* sp. The frequency with which these have been isolated from root lesions suggests that they may cause disease under certain conditions.

PHYTOPHTHORA ROT

ECONOMIC IMPORTANCE

A root and crown rot caused by *Phytophthora drechsleri* has been observed in all the principal guayule-producing areas. Although it has occurred in most of the areas in California where guayule has been planted, it caused the greatest loss on the clay soils of the Tracy-Newman district. Braun (3) observed root rot in 22 of the 25 fields surveyed in September 1943. Losses of 5 percent or more of the plants were recorded for 625 of the 3,745 acres included in his survey. By regulating irrigation practices so as to avoid waterlogging the soil these losses were materially reduced in 1944. In the Bakersfield district where the plantings have been made on lighter soils losses attributed to phytophthora rot were usually restricted to individual plants or small groups at the ends of the rows or other places in the field where water accumulated.

SYMPTOMS

Wilting, which usually develops several days after irrigation, is the first above-ground evidence of phytophthora rot. Affected plants wilt suddenly, and the leaves dry, turn gray, and generally remain firmly attached to the plant.

Root lesions are characteristically black, slightly sunken, and firm in texture (fig 6, A). The diseased zone of phloem and cortex is dark brown to greenish black on freshly dug plants and it becomes uniformly dull black on drying. The woody portion of the root at the lesion is also discolored. On newly wilted plants the lesion is ordinarily delimited by a clearly defined margin. Lesions on the taproots of wilted plants may be from 1 to 4 inches long. These develop most frequently 2 to 6 inches below the soil surface, but they may also occur deeper in the soil or at the root crown.

PREDISPOSING FACTORS

Phytophthora drechsleri requires abundant soil moisture for its development, and the type of disease which it produces is commonly called wet rot or water rot. The optimum soil temperature for the growth of *P. drechsleri* is approximately 85° F.



FIGURE 6.—*A*, Lesion on guayule root caused by *Phytophthora drechsleri*. The outer bark was removed from the lesion and immediately above it, in order to show the distinct margin and the blackened tissue of the lesion. *B*, Root infected by *Phymatotrichum omnivorum*. The mycelial strands on the surface of diseased roots distinguish plants killed by *Phymatotrichum* from those killed by other fungi.

Phytophthora rot is a warm-weather disease. In California it is active from May through September, but the greatest loss occurs in June, July, and August. Soil temperatures below 60° F. check the growth of the fungus. Consequently, phytophthora rot rarely develops during the period in which guayule is dormant.

Phytophthora rot has been prevalent only on irrigated land, but a few diseased plants have been found in dry-land plantings located on heavy soils. Such soils retained sufficient moisture from the winter rains for the fungus to cause infection when soil temperatures become favorable.

On irrigated land infection by *Phytophthora* is dependent upon saturated or near-saturated conditions of the soil for 18 hours or more, the critical period depending upon soil temperatures. Clay soils and soils with poor in-

ternal drainage are particularly difficult to irrigate without providing soil-moisture conditions favorable for infection. On lighter soils the disease develops only in low areas where water accumulates or at the ends of the rows where water is allowed to pond. When phytophthora rot occurs on such soils with good drainage, its occurrence can usually be traced to the application of a large volume of water or flooding.

CONTROL

To keep losses from phytophthora root rot to a minimum the following precautions are suggested.

(1) On irrigated fields known to present a serious disease hazard (usually those with heavy or moderately heavy soils), as much water as possible should be stored in the soil during the winter months when both the fungus and the plants are inactive. If further irrigations are required during the summer, they should be relatively light.

(2) On fields in which the disease hazard is low (usually those with sandy or loamy soils possessing good internal drainage), no particular precautions are needed except to avoid ponding or flooding at the ends of the rows and at low places in the fields. However, well-drained soils should not be saturated for more than 18 hours, especially during hot weather.

PHYMATOTRICHUM ROT

OCCURRENCE AND ECONOMIC IMPORTANCE

Phymatotrichum root rot, or Texas root rot, is caused by *Phymatotrichum omnivorum*, a fungus which is widely distributed in the calcareous soils of the Southwest and on the eastern and western coastal plains of Mexico. This fungus is indigenous to these areas and attacks both native and cultivated plants. More than 1,700 species representing field crops, garden and truck crops, deciduous fruit trees, nut trees, shade trees, shrubs, weeds, and other native vegetation are susceptible.

In 1927 and 1928, the Intercontinental Rubber Co. made experimental plantings of guayule at Pearsall, Dilley, Hebbronville, and Linn in southern Texas. In 1930 Ezekiel¹¹ observed phymatotrichum root rot in the Dilley plot. No phymatotrichum rot was found in the other plots, although there was considerable mortality from a crown rot. Root rot killed about 6 percent of the guayule plants in the Dilley plot as compared with 70 percent of the cotton plants in some nearby fields. Ezekiel confirmed the relative susceptibility of guayule and cotton by inoculation experiments.

No losses from phymatotrichum root rot were observed in any of the guayule plantings in Arizona, New Mexico, or Texas in 1942.¹² The following year the disease appeared in 1-year-old shrubs near Edinburg, Tex.¹³ In several indicator plots in Texas 2-year-old shrubs were also attacked. Dryland guayule plantings made at Raymondville and Linn, Tex., during November 1943 were showing some loss from phymatotrichum root rot in February 1944.

Phymatotrichum infestations are usually most severe on the heavier soils.

¹¹ See footnote 3, p. 2.

¹² PRESLEY, J. T. SOME DISEASES AFFECTING CULTIVATED GUAYULE IN THE SOUTHWEST DURING 1942. U. S. Bur. Plant Indus., Plant Dis. Rptr. 27: 94-96. 1943. [Processed.]

¹³ PRESLEY, J. T. OBSERVATIONS ON PHYMATOTRICHUM ROOT ROT OF GUAYULE. U. S. Bur. Plant Indus., Soils, and Agr. Engin., Plant Dis. Rptr. 28: 998-1000. 1944. [Processed.]

This is probably associated with the fact that these soils remain wet for a longer time after irrigation or rain than do the lighter ones. In general, irrigation or heavy rainfall during the summer months favors the development of phymatotrichum root rot.

Losses from phymatotrichum root rot are definitely associated with irrigation practices. One of the two indicator plots at Fort Stockton, Tex., was partially flooded each time an adjoining cotton field was irrigated; 17 percent of the plants died from phymatotrichum root rot, the greatest loss occurring in the portion receiving the most water. In the other plot, on which the irrigation water was controlled, there was less than 2-percent loss.

The severity of phymatotrichum root rot on cotton and other crops appears to be correlated with temperatures, rainfall, and soil type. The southeast portion of Texas, which warms up early in the spring and has a relatively high rainfall, also has the greatest percentage loss from root rot on susceptible crops. It is in this general area that considerable losses have occurred in guayule plantings.

SYMPTOMS

The first symptom of phymatotrichum root rot is wilting which develops when lesions girdle the taproot. Wilting is usually sudden and complete if the plants are in a lush state of growth when attacked. Diseased plants are conspicuous among healthy plants because of their light-gray, wilted leaves, which quickly become dry and curled. In plants that are not in a lush state of growth when attacked wilting is less pronounced. The lower leaves of such plants die first, and the plant may persist for some time with sparse foliage. Plants which have only a portion of the root system affected may recover during the winter, when the fungus is dormant, and resume growth the following season. The diseased root tissue is brownish and firm on newly wilted plants, but it becomes darker and shredded with age.

Similar symptoms are produced by other root-rotting fungi, and positive determination depends upon isolation of the causal organism. Field diagnosis of phymatotrichum root rot may sometimes be made by examining the roots of affected plants with a hand lens. Fine, yellowish to brownish, fuzzy mycelial strands are usually present on the surface of the roots of plants killed by *Phymatotrichum* (fig. 6, B).

The vegetative (*Ozonium*) stage of *Phymatotrichum* consists of strands and masses of interwoven mycelium. The spore-mat (*Phymatotrichum*) stage is usually produced during August or September on moist soil surfaces near dead or infected plants, but apparently it has no function in perpetuating the fungus. Sclerotia, or resting bodies, formed in the soil near diseased roots enable the fungus to survive unfavorable conditions. The fungus spreads from plant to plant along the roots or for short distances through the soil independently of roots. Although the fungus is active during most of the year, high temperatures are particularly favorable for its development. The fungus may overwinter either as vegetative mycelium on infected plants that are still living or as sclerotia.

CONTROL

Wherever possible guayule should not be planted on land known to be heavily infested by *Phymatotrichum*. This is especially true in southeastern Texas where the summer rainfall furnishes optimum moisture for the disease to develop. In other areas of Texas and the Southwest where moisture conditions are much less favorable for the disease, guayule may be planted with

reasonable safety on the lighter nonirrigated soils. Heavy soils under irrigation, if already infested by *Phymatotrichum*, are generally hazardous for guayule because of root rot regardless of location.

SCLEROTINIA ROT

ECONOMIC IMPORTANCE

Root rot caused by *Sclerotinia minor* and *S. sclerotiorum* has been observed in two plantations of guayule.¹⁴ In one field in the Salinas Valley of California, fewer than 1 percent of the plants were killed over a 2-year period. Most of the loss was caused by *S. minor*. In a 20-acre field in Arizona approximately 5 percent of the plants were killed by *S. sclerotiorum* during the first season.

SYMPTOMS

Wilting of affected plants is the first symptom of sclerotinia rot. The causal fungus usually attacks the taproot from 3 to 6 inches below the soil surface and causes a lesion which girdles the root.

The presence of sclerotia on the surface of the plant or in the diseased tissues distinguishes sclerotinia rot from all others. Sclerotia may not be present on newly formed lesions, but identification can usually be made by the soft, shredded appearance of the rotted tissue, which does not differ materially in color from the healthy. Wefts of white mycelium are also commonly present on the surface of the diseased roots.

Top infections from ascospores of *Sclerotinia sclerotiorum* have not been observed in field plantings.

CONTROL

Root rot caused by *Sclerotinia* spp. has not been of general occurrence and ordinarily should not cause sufficient loss to justify control measures. However, before guayule is planted in fields known to be heavily infested by *Sclerotinia*, the soil should be worked and allowed to dry thoroughly so as to kill the mycelium of the fungi.

BACTERIAL ROT

ECONOMIC IMPORTANCE

A root disease caused by an unidentified bacterium and in the advanced stage frequently characterized by stem lesions has caused severe losses in several irrigated plantings in the San Joaquin Valley of California. Diseased plants with similar root and stem lesions have also been noted on several indicator plots in Texas.

SYMPTOMS

The first indication of the disease is similar to that of other root rots, namely wilting of the affected plant. Frequently wilting is progressive, starting with one or more of the lower branches and followed in a few days by the remainder of the top. If the plant is vigorously growing when attacked, wilting may be sudden and complete. If it is in a less succulent condition, the leaves may gradually dry without noticeable wilting. By the time wilting is observed, most of the taproot is badly diseased. The surface of the diseased portion of the taproot is covered with black, resinous masses to which the soil adheres when the plant is pulled from the ground. In the advanced stage

¹⁴ BRAUN, A. J. OBSERVATIONS ON SCLEROTINIA ROOT ROT OF GUAYULE. U. S. Bur. Plant Indus., Soils, and Agr. Engin., Plant Dis. Rptr. 28: 982-984. 1944. [Processed.]

of the disease these resinous masses cause the root lesions to appear swollen. The affected bark is soft, watery, and more or less spongy, separating readily into layers. It is light brown or dark brown, depending upon the age of the lesion; occasionally it has a vinaceous tint. The wood of the lower portion of the taproot is usually blackened, but this discoloration disappears in the upper part of the root. However, a red or pinkish ring in the cambium and youngest wood may extend for some distance above the lesion.

Contrary to the condition observed in other root rots, the lesions continue to develop after the plants wilt; if not stopped by drying they may advance for some distance into the stems and smaller branches. The progress of the lesions is marked by conspicuous black, resinous masses, or bubbles, on the stems.

In the stems where it is possible to observe the advancing margin of the lesions, the cortex seems to be involved first and progressive deterioration of the associated tissues follows. In some cases the resin exudate is thin and spreads over the surface in a brownish film, which later becomes black.

CONTROL

Bacterial rot has been noted only on irrigated plantings and has been serious only in localized areas which receive the most water because of topography or location. Control, therefore, consists in judicious handling of irrigation, especially avoidance of overwatering of local areas in the fields.

DROWNING

Broyer¹⁵ demonstrated that guayule roots have a relatively high oxygen requirement and that plants grown under favorable aerobic root conditions are very sensitive to subsequent reduction in their oxygen supply. Prolonged periods of flooding, referred to as drowning, generally result in the death of guayule. Roots of drowned plants are soon rotted by invading organisms.

Heavy soils and those with a shallow claypan or hardpan are readily waterlogged when flooded. Dortignac and Mickelson¹⁶ demonstrated the relation between soil type, infiltration capacity, and the survival of guayule for the Harvey Smith plantation near Salinas. In this plantation many plants died from drowning during the 1942-43 and 1943-44 rainy seasons.

Plants in areas where water stands during the winter months often fail to develop new growth in the spring. Usually all or a part of the roots are rotted and the plants gradually die.

In irrigated fields where prolonged flooding occurs during the summer months, when soil and air temperatures are high and the plants are growing vigorously, the symptoms of drowning are different from those developing in the winter and death occurs more rapidly. Sudden wilting of the foliage of plants occurs within a few days after flooding. The feeder roots and the lower portion of the taproot die and eventually rot. The rotted tissue usually is whitish or bluish and the bark, which can be readily pulled from the woody cylinder, is soft and soggy and has a disagreeable odor. Later the root becomes brown or black.

¹⁵ BROYER, T. C. OBSERVATIONS ON THE GROWTH OF GUAYULE UNDER GREENHOUSE CONDITIONS. Univ. Calif. Rpt. 1945. [Processed.]

¹⁶ DORTIGNAC, E. J., and MICKELSON, G. A. OBSERVATIONS AND RESULTS OF SOIL MOISTURE STUDIES ON THE HARVEY SMITH PLANTATION, SALINAS DISTRICT. Emergency Rubber Project Rpt. 1944. [Unpublished.]

Temperature is an important factor in injury from drowning. Because respiration is increased by a rise in temperature, the oxygen requirement of the roots is greater. The effect of temperature on drowning was demonstrated by a greenhouse experiment in which plants were grown 7 days at temperatures ranging from 70° to 100° F. in waterlogged soil and in soil kept at approximately field capacity. In the waterlogged soil all 12 plants at 100° wilted after 2 days; at 90° wilt developed on the third day and at 80° on the fifth day. None of the plants in waterlogged soil maintained at 70° were severely wilted after 7 days, although temporary wilt developed in the afternoons of the sixth and seventh days. No wilting occurred at any temperature in the checks maintained at field capacity.

CROWN ROT

A crown rot caused by *Sclerotium bataticola* has been observed in 2-year-old dry-land guayule plantings near Pearsall, Tex.¹⁷ The disease developed during July and August 1944 after a prolonged period of hot, dry weather; it was characterized by dark-brown sunken lesions which developed at or near the ground line. The lesions gradually enlarged around the point of infection, causing a progressive dying of the top. During July and August it was possible to find plants in all stages of the disease, from those in which partial girdling had killed one or more branches to those in which the entire top was killed. In contrast to plants killed by a root rot, the root systems ordinarily remained alive for some time after the tops had died from the girdling lesions at the ground line.

Field counts made in August 1944 at Pearsall, Tex., gave 7.6 percent of the plants in the 10-inch spacings affected by the disease, 11 percent in the 20-inch, and 13.9 percent in the 40-inch. Cooler weather and rain checked the disease, and many of the affected plants eventually recovered.

VERTICILLIUM WILT

ECONOMIC IMPORTANCE

Verticillium wilt has been observed in a number of guayule plantations. Mild infections are frequently not recognized because external symptoms other than stunting are lacking. For this reason, reductions in yield caused by verticillium wilt may not be attributed to this disease.

It is difficult to estimate accurately losses caused by verticillium wilt. Limited studies have shown that stunting of the plants, not visible from casual observation, caused losses up to 50 percent in dry weight of 1-year growth. Areas in a number of fields contained many dead plants and many obviously stunted. Out of approximately 8,000 acres in the Bakersfield district, 375 were heavily affected and 725 contained scattered infections in the fall of 1943. In the Salinas district 230 out of 5,500 acres were known to be affected in varying degrees by the disease.

SYMPTOMS

Symptoms of verticillium wilt vary in plants of different ages. Transplants set out in infested soil usually grow to 6 inches or more in height before wilting occurs. The first evident symptom is a wilting of the lower leaves. These turn yellow after several days and gradually become brown and dry.

¹⁷ PRESLEY, J. T. A DISEASE OF GUAYULE CAUSED BY *SCLEROTIUM BATATICOLA*... U. S. Bur. Plant Indus., Soils, and Agr. Engin., Plant Dis. Rptr. 28: 936. 1944. [Processed.]

Occasionally a single branch will wilt before the rest of the plant is affected. After this initial wilting some of the plants apparently recover and resume normal growth; others continue growth at a reduced rate, the older leaves wilt and die, and the newly formed leaves are smaller than in healthy plants. The more severely affected plants die. The root systems of plants infected by *Verticillium* are usually affected by root rot, the degree of injury corresponding to the severity of the symptoms.

The most accurate symptom for diagnosing verticillium wilt is a discoloration in the wood of the stems and roots (fig. 3, *B*) resulting from the presence of the fungus in the vessels. The walls of the cells turn brown, and the lumina of many of the vessels become filled with a yellowish or brownish substance called wound gum.

The guayule strains vary considerably in their ability to recover from *Verticillium* infections (12). Plants of strain 109 ordinarily do not recover, whereas those of other strains, especially 405, 407, and 416, show a high percentage of partial or complete recovery. Strain 593, the one most commonly planted, is intermediate in susceptibility and disease expression. External symptoms are usually not apparent in most strains infected after the first season. If symptoms are present they are similar to those caused by drought. Strain 109, however, may become infected and die at any age.

PREDISPOSING FACTORS

Favorable temperatures (65° to 80° F.) are necessary for infection and development of verticillium wilt. In the Bakersfield district the disease is most active in the spring and autumn when mean air temperatures approximate 70°. The disease is most prevalent in the Salinas district in July, August, and September, when favorable temperatures occur.

Considerable experimental work has been done on the relation of soil moisture to infection. Verticillium wilt develops readily over a wide soil-moisture range. Prevention of infection was obtained only by maintaining plants in soil that was near the wilting point and therefore too dry for satisfactory growth. The ability of *Verticillium albo-atrum* to cause infection of guayule over a wide soil-moisture range makes impractical prevention of infection by controlling irrigation.

CONTROL

At present there are no control methods known for verticillium wilt except avoidance of infested land or the use of a resistant strain such as 405.

RUST

A leaf rust caused by *Puccinia parthenii* was observed in 1945 on both wild and cultivated guayule in Mexico. Lloyd (9) reported the rust on cultivated guayule in Mexico in 1908 and found it generally distributed on wild shrubs in the same area. It has been collected on a closely related species of *Parthenium* in Texas (2) but has not been reported on guayule from the United States.

The fungus attacks the older leaves producing small, inconspicuous specks, or pustules. Diseased leaves were common on plants 2 years old or older that had received abundant water and had developed large leafy tops. Infected leaves were rare on plants growing under dry conditions mainly because such plants had shed most of the older leaves and retained only the terminal clusters of new leaves. Under ordinary growing conditions the rust appeared to cause little damage to guayule.

DODDER INJURY

Many wild and cultivated plants as well as guayule are parasitized by dodder (*Cuscuta* sp.). Lloyd (9) observed dodder on native guayule in Mexico. It was found on seedlings in a nursery near Indio, Calif., and on field-planted guayule near Bakersfield.

The upper portions of parasitized guayule plants were covered with a dense mass of dodder stems. The dodder had produced many seeds, which were in a favorable position to be gathered by the mechanical pickers used in collecting guayule seeds. Dodder seeds and those of guayule are approximately of the same weight and size, and it is difficult to separate the two by mechanical means when mixed. Furthermore, dodder seeds are not harmed by the hypochlorite treatment used for guayule. Since dodder is commonly spread from place to place as a seed contaminant, it should be carefully eradicated from areas used for the production of guayule seeds.

To prevent the introduction of the parasite to field plantings, dodder-parasitized plants should be eradicated from the seedbeds.

DIEBACKS

Two distinct types of dieback have been observed on guayule, namely that caused by the fungus *Diplodia theobromae* and that associated with drought.

Diplodia dieback developed in southern Texas during late summer and fall after heavy rains and was most serious on succulent plants in areas where the tops formed a continuous canopy over the ground.¹⁸ The early stage of the disease is characterized by the dying of the leaves and small branches; however, if conditions are favorable for continued development of the disease larger branches or the entire plant may be killed (fig. 7, *A* and *B*). Dieback caused by *Diplodia* may be identified by the presence of small, black, elongated fruiting bodies of the fungus which break through the bark, often in sufficient numbers to give the diseased bark a roughened and blackened appearance (fig. 7, *C*).

Dieback associated with drought was first observed in the late summer of 1943 in several indicator plots in Texas and Arizona. The symptoms of this dieback were drying and eventual dying of the terminal leaves and small branches. Later in the season after rains the dried-out leaves and branches were attacked by fungi, mainly a species of *Alternaria*. In the spring of 1944 similar injury was widespread in several fields near Bakersfield, Calif., and was observed in other districts. In the Bakersfield district severe moisture stress occurred late in the fall and winter of 1943, and the dieback was not evident until growth was initiated in the following spring.

Although a species of *Alternaria* has been isolated consistently from the dead twigs and leaves, it is not considered the primary cause of the dieback. *Alternaria* and other fungi attack the weakened and dead parts of the plant when sufficient moisture becomes available for their development. The extent of damage caused by these fungi to drought-weakened parts of the plants which might otherwise recover is not known, but it is believed to be relatively small.

¹⁸ PRESLEY, J. T. DIPLODIA DIEBACK OF GUAYULE. U. S. Bur. Plant Indus., Soils, and Agr. Engin., Plant Dis. Rptr. 29: 64. 1945. [Processed.]

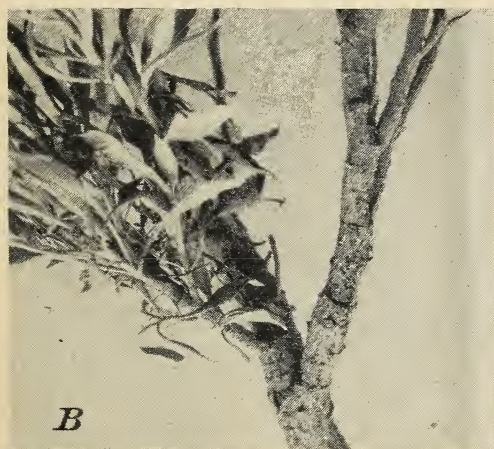


FIGURE 7.—*A*, Two-year-old guayule plant with one branch killed by *Diplodia theobromae*; *B*, the girdling lesion at the base of the dead branch shown in *A*; *C*, portion of the plant killed by dieback, showing fruiting bodies of the causal fungus.

NONPARASITIC INJURIES

Many factors other than disease cause injury or death to guayule in the field. The damage caused by cultivators, seed-gathering machines, or other equipment is obvious. However, the causal agent for injuries that do not develop immediately is sometimes difficult to determine. Nonpathogenic injuries of this type are frequently caused by wind, drought, frost, oil spray used for weed control, or chemicals used to treat the soil for the same purpose. Other agents that cause damage to field-grown guayule include rabbits, ground squirrels, grazing animals, and insects. In many fields the aggregate loss from nonpathogenic injuries is greater than that caused by disease.

WIND INJURY

Strong winds frequently cause mechanical injury to localized areas on the leaves and flower stalks at points where they continually rub against

each other. Affected leaves have striated, dark-green markings which later turn brown. Although considerable injury may be evident on the foliage, this condition does not appear to affect greatly the growth of the plants.

Another type of wind injury, caused by wind-blown sand, has been observed in localized spots in several plantations. The affected plants are deformed and stunted as the result of the combined erosive action of the wind and sharp particles of sand that strike against the plant.

DROUGHT INJURY

Drought injury to guayule has been observed mainly on sandy or gravelly soils. In the initial stages of water deficiency the leaves of affected plants gradually become dry and curl. If drought conditions persist, most of the leaves drop off and in extreme cases the ends of the branches progressively die toward the crown. After prolonged periods of heat and drought affected plants may fail to revive after rains or irrigation.

The conditions under which a plant is grown determine to a considerable extent its ability to withstand long periods of drought. Plants grown with a limited supply of moisture are better adapted to withstand drought than those that have been well supplied with water during periods in which temperatures are favorable for vegetative growth. Plants with large, bushy tops tend to exhaust their water supply more quickly than those with small tops.

Severe drought injury developed on an indicator plot in the northern Sacramento Valley of California. This plot, located on a silt loam 4 to 7 feet thick underlain with coarse river sand, is in an area which receives approximately 20 inches of rainfall each year during the winter months. During the first year this amount of moisture was ample for continuous growth throughout the season. During the second year the plants had grown so large that the water supply was exhausted by midsummer. By November the leaves were dry and the plants appeared severely stressed. The following spring many plants did not revive. The greatest mortality occurred where the plants were spaced 12 inches apart. Fewer plants succumbed where they were spaced 24 and 30 inches apart.

Drought symptoms have been occasionally confused with those of verticillium wilt. Usually drought is common to an area corresponding to the distribution of a soil type such as a sandy or gravelly area in a field. Verticillium wilt is confined to groups of diseased plants interspersed with slightly affected or apparently healthy plants. Plants affected by *Verticillium* can be distinguished from those suffering from drought by the brownish discoloration in the central woody portion.

INJURY FROM HEAT OR COLD

Ordinarily guayule is not injured by high temperatures provided sufficient moisture is present in the soil to prevent drought symptoms. However, tender foliage of newly sprouted guayule seedlings may be severely injured or killed by high temperatures if in contact with dry clods or loose soil. Seedlings in the nursery at Indio, Calif., were killed by the removal of the tops which exposed the basal portion of the stems to direct sunlight and resulted in cankers at the root collar. Newly emerged seedlings in field seedings have been killed by high temperatures as have those in the nursery.

Indicator plots in New Mexico and Texas have provided information on the effect of low temperatures on guayule. In one irrigated experimental planting in the upper Pecos Valley near Roswell, N. Mex., most of the

plants were killed in the winter of 1942-43. The lowest temperature recorded was 7° F. Plants in plots at El Paso, Pecos, and Balmorhea, Tex., were also injured by cold. Ordinarily guayule will withstand temperatures as low as 10° without serious injury, and plants in natural stands in Texas have survived lower temperatures of short duration.

Lush growth on recently planted stock is susceptible to damage at temperatures ordinarily not considered dangerous. At Edinburg, Tex., the tender leaves of transplants were damaged by a temperature of 26° F., which prevailed for a few hours. The plants recovered, and within a few weeks it was impossible to observe any damage.

INJURY FROM CHEMICALS USED FOR WEED CONTROL

Oil used for weed control in plantations has been observed to cause injury under certain conditions. Oil spray applied after the leaves have matured ordinarily causes but limited burning of the foliage. The same is true of sprays applied in the fall or winter when the plants are dormant. The most hazardous period to apply oil is spring when new growth is starting. Oil in contact with partially opened buds and newly expanded leaves may kill them, and growth is delayed until new buds are initiated. In fields on which oil has been used for weed control plants are sometimes killed at the ends of the rows by a heavy dose of oil. This excessive oiling of small spots occurs where the spray is turned on as the machine starts a new round in the field.

Carbon bisulfide used for the control of morning-glory has also caused the death of guayule in treated areas. In several cases the plants were affected when planted too soon after the soil had been treated.

INJURY FROM SOLUBLE SALTS

Reference has been made under "Preestablishment Loss and Predisposing Factors" (p. 29) to the effect of high surface salt concentration on the survival of transplants. An example of salt injury to established plants has been observed at Edinburg, Tex. Seedlings planted in March made rapid growth until August, after which the leaves on the affected plants gradually wilted and died. On examination it was found that the roots had come in contact with a salt layer in the soil at a depth of approximately 12 inches. Numerous, short, thickened, lateral roots were formed which spread horizontally in the soil above the salt layer. During the spring when moisture was abundant the salt concentration in the top foot or so of the soil was below that injurious to the plant. Later, as the soil dried the salt concentration increased, resulting in the death of the plants. This condition was observed in two low spots each of which was approximately 100 feet in diameter.

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